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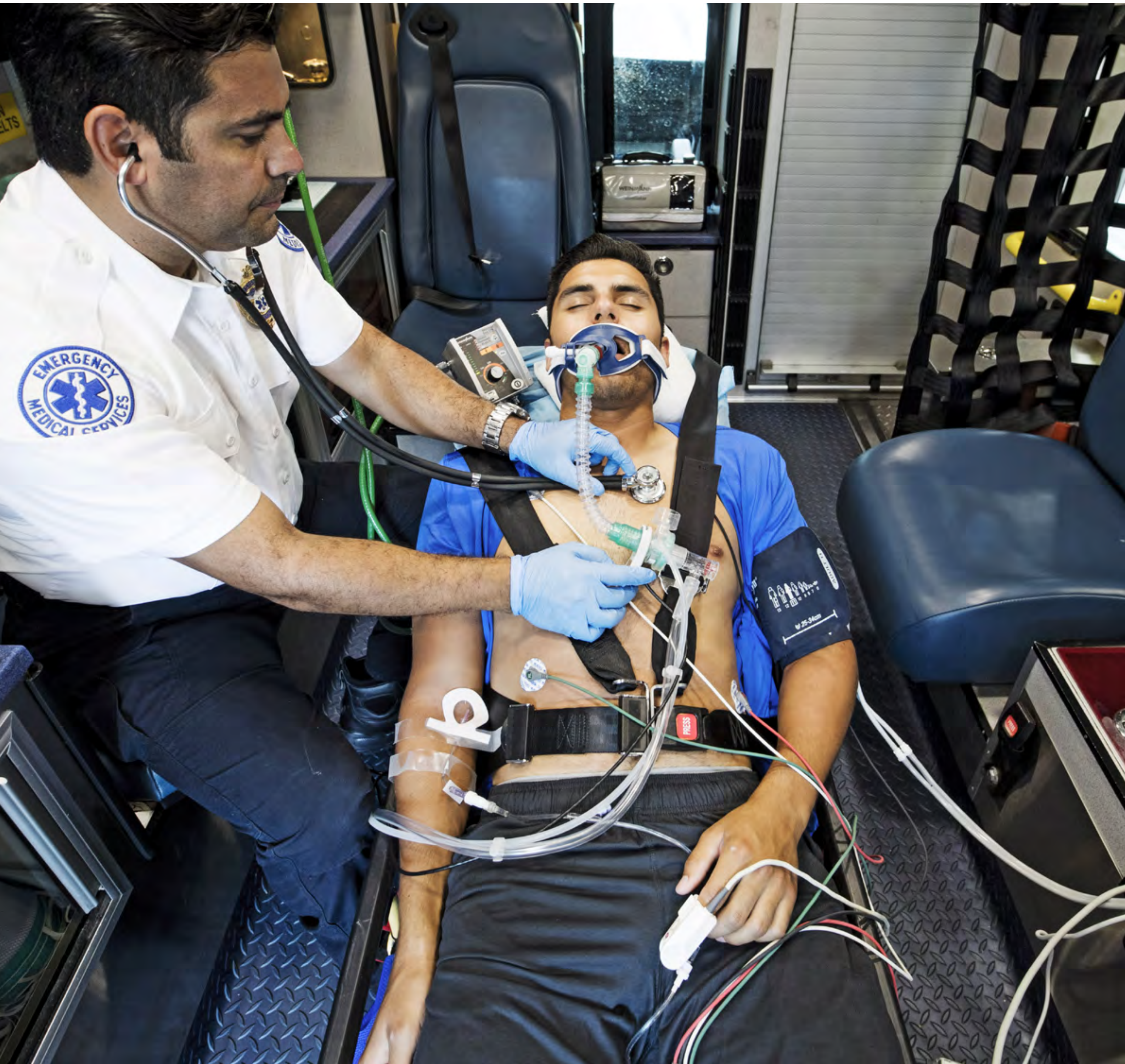
Automated Ventilation in the Prehospital Environment

Mechanical Ventilation Offers a Safer and More Effective Alternative to Manual Ventilation



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The WEINMANN Emergency EMS Medical Advisory Panel is a select group of clinicians who have insight into the culture and mindset of the EMS and healthcare community. They include EMS medical directors and researchers who are among leading experts in resuscitation and prehospital medicine. The group contributed expertise, editorial advice and review for this paper. Final responsibility for authorship and the content of the report was retained by WEINMANN Emergency.

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Abstract

Patients with acute life-threatening illness in the out-of-hospital setting often require assisted ventilation to ensure adequate inhalation of oxygen as well as exhalation of carbon dioxide. Ventilation is considered an essential skill in the out-of-hospital setting, but large variation exists in both how it is performed and patient outcomes. Prehospital providers may give breaths with a bag attached to a facemask, a supraglottic airway or an endotracheal tube. When performing manual ventilation with a bag, healthcare providers deliver breaths at a wide range of rates, tidal volumes and pressures, frequently deviating from recommended evidence-based practice guidelines. Such variation in care is associated with poor outcomes in patients with cardiac arrest or traumatic brain injury and may be harming other patient populations as well.

Overcoming this wide variation in manual ventilation practices would require extensive training and practice, along with vigorous quality assurance and feedback. This may be difficult to achieve without improved real-time methods of measuring ventilation rate, volume and pressure. Portable mechanical ventilators are intended to provide consistent oxygenation, as well as ventilation rate, volume and pressure. Use of these medical devices could reduce variations associated with human factors and remove a stressful and resource-heavy task, freeing up clinicians to focus on other critical assessment and treatment decisions. In addition, it would facilitate research and quality improvement efforts to expand knowledge of the impact of ventilation rates, volumes and pressures on outcomes.

Introduction

The importance of ventilation in the management of critically ill or injured patients has been recognized for centuries. [40 Slutsky 2015] In modern practice, emergency medicine clinicians, from first responders to physicians, have long been taught that the ability to ventilate through a patent airway trumps just about any other concern. Without the inward movement of oxygen and outward movement of carbon dioxide, patients cannot survive.

Despite awareness of ventilation's importance, little is known about the impact of different modes of ventilation in the out-of-hospital setting. In patients with acute, critical conditions, such as cardiac arrest, research to date has focused on choice of airway device. [33 Ong] Some observational studies have suggested the importance of ventilation rates in small subsets of patients, such as severe head trauma victims, but in general measuring and evaluating the relationship between ventilation's components and patient outcomes in the prehospital setting has remained elusive. [29 McMullan]

What seems clear is that ventilation matters—research shows that how and when it is performed is associated with patient outcomes. Yet in prehospital emergency care, manual ventilation is often delegated to the least experienced or educated responder on the scene. Multiple observational studies have demonstrated significant inconsistency during ventilation with a bag-valve (both with a mask and after placement of an advanced airway), with rates and volumes varying widely. [29 McMullan, 37 Siegler] It is not simply a knowledge or a training issue—even experienced paramedics struggle to ventilate at proper rates and volumes, which is not surprising given the lack of tools to measure tidal volumes and rates in the field, the chaotic and sometimes stressful nature of prehospital medicine and the multi-tasking required of EMS clinicians.

These are not new problems. As early as the mid-1990s, researchers were finding that ventilation with a bag-valve in the prehospital setting frequently did not meet recommended guidelines for several parameters. [21 Auble, 61 Baskett, 12 Dockery] In 2004, Aufderheide et al published a landmark report that showed that even after retraining, emergency medical services (EMS) clinicians continued to deliver excessive ventilation during cardiac arrest—potentially hurting patients' chances of survival. Hyperventilation has also been associated with worse outcomes for patients with traumatic brain injury. [11 Davis]

Although multiple studies have shown that it is difficult for clinicians at all levels to maintain the appropriate rate and tidal volume with a bag [21 Auble, 24 Lee], mechanical ventilators are rarely used in the prehospital setting in the United States. One examination of more than 28 million EMS records from across the country reported ventilator use in fewer than 80,000 cases. [14 El Sayed] Mechanical ventilators offer a safe alternative to bag-valve ventilation and allow clinicians to deliver consistent and controlled tidal volumes at a determined rate. "Providing a ventilator for every ambulance should be considered," Wayne et al stated in 2001, "along with the priorities for other equipment, because alternate techniques for ventilation have proved inadequate and therefore unacceptable." [48 Wayne]

So why have more EMS systems not sought out better ways to ventilate their patients? One reason is that components of ventilation are rarely measured and tracked. Quality improvement activities related to care of patients with cardiac arrest have, for good reason, focused on chest compressions and defibrillation. Airway management is typically viewed through the lens of whether or not a patient was successfully intubated. While there is a recent push to better measure and track physiologic factors such as SpO_2 and $EtCO_2$ and to evaluate these as part of quality assurance and quality improvement efforts, regular measuring and tracking of ventilation rates and volumes in the field remains rare. EMS leaders are left with little knowledge of how well their systems are performing.

This might sound somewhat familiar. Two decades ago, EMS professionals were coming to terms with the same issues related to chest compressions. It was believed that a wide variation existed in how CPR was believing delivered—not just from one community to another, but within EMS systems as well.

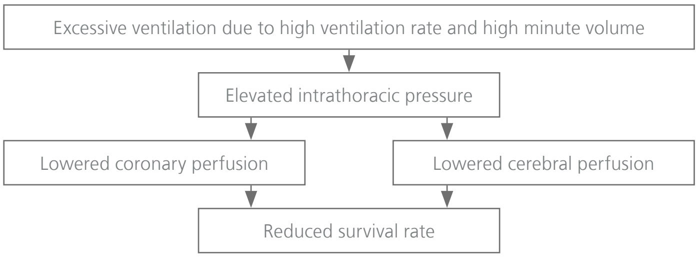
Until systems started routinely measuring CPR processes, many agencies assumed they did not have a problem.

Now, most high-performing EMS systems have accepted that delivering consistent, effective chest compressions takes practice, focus and often the assistance of technology, from metronomes to real-time feedback to mechanical CPR devices. It is time to turn the same critical eye on prehospital ventilation and recognize that there is a better way to care for patients and improve outcomes.

Limits of Manual Ventilation in Cardiac Arrest

The potential harm caused by manual ventilation during the resuscitation of cardiac arrest patients has been well documented. Perhaps the most significant problem is simply the lack of real-time awareness of ventilation rates and volumes delivered. Aside from crude visual metrics such as chest rise and end-tidal CO_2 waveform in exhaled breaths, bag-masks, whether used with facemasks, supraglottic airway devices or endotracheal tubes, provide limited guidance or feedback to the user, and no reliable method of measuring volume or pressure. Especially in the prehospital setting, where providers face distractions and competing priorities, delivering consistent breaths can be difficult—and the results of improper ventilation can be disastrous.

1a)



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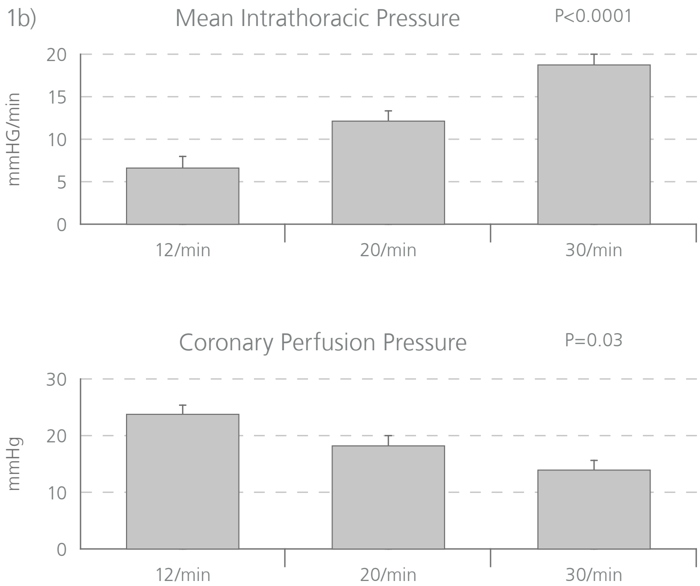

Fig 1 – a) *The impacts of excessive ventilation on patients in cardiac arrest.*

Fig 1 – b) *In a study of pigs in cardiac arrest, increasing ventilation rates were associated with increased intrathoracic pressure and decreased coronary perfusion pressure. [4 Aufderheide and Lurie]*

Hyperventilation

The tendency of most healthcare providers while using a bag-valve to ventilate is to deliver breaths at too fast of a rate. [Sall] The inclination toward hyperventilation in the prehospital setting has been well-documented, especially in patients in cardiac arrest. [3 Aufderheide] Aufderheide et al reported in their 2004 paper that prehospital providers were ventilating cardiac arrest patients at an average rate of 37 breaths per minute, well above the 12 to 15 recommended at the time. [4 Aufderheide and Lurie] After retraining, the rate decreased but continued to vary significantly from the guidelines; in addition, when the rate decreased, the duration of each breath increased, leading to prolonged periods of positive pressure in the thoracic cavity—potentially hurting patients' chances of survival. This hyperventilation due to excessive rates or tidal volumes can have many adverse physiologic effects. It has been shown to decrease cardiac preload, cardiac output and coronary perfusion pressure [Aufderheide], which are correlated with adverse outcome in animals and humans with cardiac arrest. [20 Kern; 35 Paradis]

Gastric inflation

Short, pressure-driven ventilations and ventilations with durations longer than one second can cause gastric inflation [15 Fitz-Clarke 2018], which has been associated with decreased cardiac output [8 Braun] and other complications, including regurgitation, aspiration of stomach contents and even gastric rupture. [41 Smally, 43 Spoormans] More consistent, controlled mechanical ventilations are posited to reduce pressure build-up in the stomach, so as to reduce the likelihood of vomiting, aspiration of stomach contents and subsequent respiratory complications. [44 Stallinger 2002]

Barotrauma

Manual ventilation often results in higher peak airway pressures, possibly due to hyperventilation compounded by the lack of methods to measure or limit airway pressures during resuscitation. [46 Turki] This may be associated with barotrauma and other injuries, complicating the patients' post-resuscitation recovery. [25 Malik]

Hypoventilation

Although hypoventilation by EMS providers has not been documented or studied as much as hyperventilation, some studies have indicated that it does occur in some cases [29 McMullan 2018]. Hypoventilation—caused by too slow a respiratory rate, too small tidal volumes or inadequate mask seal—could cause hypoxemia or hypercapnia. Although little is known about the impact of hypoventilation on cardiac arrest patients, some studies do indicate an association between higher arterial oxygen levels and return of circulation, while others point to the importance of maintaining normoxia following ROSC in order to achieve survival. [31 Newell]

Why Manual Ventilation is a Difficult Task

Manual ventilation can appear like a simple task that requires little effort. This may explain why, despite the known deficiencies, manual ventilation remains a staple of prehospital care. After all, just about anyone can hold a mask and squeeze a bag. But it turns out that performing manual ventilation correctly is not quite that easy. In fact, the evidence shows that most healthcare providers struggle to perform it consistently—and the impact that variability is having on our patients remains unknown.

Resources

The most recent American Heart Association (AHA) and European Resuscitation Council (ERC) evidence-based practice guidelines for treatment of patients with cardiac arrest recommend that two people focus on ventilating: one to maintain a mask seal and open the airway, and another to squeeze the bag. [42 Soar] Yet many protocols for high-performance CPR only assign one provider to manage the airway and provide manual ventilation. The emphasis on chest compressions and other aspects of resuscitation may come at the expense of focusing on providing high-quality ventilation. Perhaps because it is considered an essential skill for EMS clinicians at every training level, ventilating with a bag-valve-mask is often handled by a provider with less medical education and experience, while paramedics focus on "advanced" skills such as obtaining venous access, administering medications and identifying and treating dysrhythmias.

Environment

It has been suggested that the stressful, sometimes frenzied environment associated with prehospital care might make manual ventilation even more difficult. [36 Pitts 2004] The emphasis in prehospital care is often speed—get to the patient quickly, identify the problem quickly, and begin treating any critical issues quickly. Even efforts to perform rapid chest compressions at a rate of 100-120 per minute might influence ventilator rates during cardiac arrests—one group of researchers found differences in both average tidal volume and peak airway pressures based on whether a metronome for chest compressions was set at 100 bpm compared to 120 bpm in a simulation study. [30 Na 2017]

Measurement

Some indirect measurement and feedback is widely available, such as pulse oximetry and capnography; but direct measurement of tidal volume, airway pressure and other ventilation-related factors in EMS is rare. In addition, several studies have demonstrated the impact of both the clinician's grip technique as well as physical characteristics of the patient and clinician on ventilation rate, volumes and pressures. [7 Bassani, 18 Hess, 27 McCabe, 22 Kroll] While guidelines recommend ventilating just enough for visible chest rise, there is scant evidence to support the effectiveness of that method in the field. Without any reliable way of measuring rate, tidal volumes, airway pressures and other factors associated with ventilation, prehospital providers manually ventilating their patients are left in the dark, not really knowing whether their ventilations are compliant with guidelines.

Ventilation in Clinical Conditions Other Than Cardiac Arrest

Cardiac arrest is not the only situation where the variation associated with manual ventilation may have a deleterious effect on patients in the prehospital setting. In fact, there may be a number of patients for whom hypo- or hyperventilation can impact their outcomes. For example, ventilation rates and volumes can impact blood gas levels; one study comparing manual to mechanical ventilation while moving patients in the hospital found that manual ventilation, when compared to mechanical ventilation, led to marked respiratory alkalosis [19 Hurst 1989].

One area in which the impact of prehospital ventilatory variation has been studied extensively is traumatic brain injury. Hypoventilation and subsequent hypoxemia can potentially lead to worse outcomes in patients who have just suffered a traumatic brain injury (TBI). In several studies, TBI patients who had episodes of hypoxia in the early stages following their injury experienced greater mortality. [10 Chesnut, 11 Davis] At the same time, hyperventilation in head injured patients intubated by prehospital providers was also associated with worse outcomes [Davis], possibly due to vasoconstriction caused by eliminating too much CO_2. Other research has also found associations between the quality of prehospital ventilation and mortality for patients with a brain injury. [13 Dumont, 47 Warner]

As with cardiac arrest, hyperventilation in traumatic brain injury and other clinical situations may also decrease cardiac output. Avoiding hyperventilation is one of the tenets of the Brain Foundation's Guidelines for Prehospital Management of Traumatic Brain Injury: "Adequacy of ventilation is dependent not only on the ventilation rate, but also on the tidal volume of oxygen delivered, and the pressure under which the tidal volume is delivered." [5 Badjatia]

Benefits of Mechanical Ventilation

Portable mechanical ventilators are intended for use with patients who are being treated or transported in the field or within a health-care facility. In the United States, prehospital use of portable ventilators is largely limited to air medical transport and critical care interfacility transfer ambulances. In contrast, many countries throughout the rest of the world mandate use of prehospital mechanical ventilation for patients who require ventilation. For example, the European Union standard for medical vehicles and their equipment, EN 1789, requires mechanical ventilators for ambulances providing advanced medical care.

Mechanical ventilators deliver ventilations at a consistent, user-derived oxygen dose, ventilation rate and tidal volume, with or without additional medications. "Controlling inflation time, flow rate, and flow waveform with a mechanical ventilator may be the best solution to control and limit peak inflation pressure for a given tidal volume," wrote Herff and Wenzel in a comprehensive look at ventilation during resuscitation, "but these variables are not controlled easily during manual ventilation." [17 Herff]

Pressure limits

Mechanical ventilators with integrated pressure limits avoid excessive peak airway pressures that sometimes can occur with manual bag ventilation. [26 Marjanovich] Pressure is uniform with each breath, and is not impacted by the strength of the clinician or other extrinsic factors. In addition to controlling pressure, ventilators also monitor airway pressures and alert the caregivers to potential issues.

Controlled oxygenation

Many mechanical ventilators allow users to control the percent of oxygen being delivered to the patient, which can be critical for many patients on long-term ventilation. In the setting of cardiac arrest, it is unclear whether hyperoxia associated with the delivery of 100% oxygen by prehospital providers during resuscitation or following restoration of spontaneous circulation (ROSC) has any impact on outcomes. Some observational studies and limited clinical trials indicated that hyperoxia after ROSC is associated with poorer outcomes, while other researchers reported no connection between the two. [34 Patel, 28 McKenzie]

Controlled volume and rate

Mechanical ventilators deliver a consistent volume with each breath, often at parameters that can be set by the clinician and adjusted to best fit the patient's needs. Whether a patient is being ventilated with a mask or through an advanced airway device, providers can be assured that the mechanical ventilator delivers the same tidal volume each time. [23 L'her]

Mechanical ventilators can provide a consistent rate, eliminating one of the most persistent errors made by prehospital and other medical providers when ventilating with a bag [32 Nikolla]. Knowing that the ventilation rate will remain consistent allows them to focus on more adequately assessing the quality of ventilation and other patient factors.

Crew safety and decreased need for resources

Mechanical ventilation eliminates the need for a second provider during ventilation with a facemask, as the clinician can focus on maintaining a mask seal and observing the patient, without having to worry about squeezing a bag. This is still true even when an automated rate has not been set—such as during the initial, immediate response or CPR—if the mechanical ventilator allows a provider holding the mask to trigger each breath while still maintaining a two-handed seal.

For EMS transport of patients who are ventilator-dependent, mechanical ventilators provide a safe and more efficient alternative to manually ventilating the patient throughout transport.

In areas where paramedics frequently respond as crews of only two people, this means medics can be assured that ventilations are being delivered even as they have to tend to another critical task—all while they are safely seat-belted in the ambulance. In one small study comparing the use of bag-valve ventilation to automatic transport ventilation, paramedics reported the automatic ventilator made it easier for them to provide patient care, accomplish additional tasks and document their care. [49 Weiss] This experience is analogous to the use of mechanical chest compression devices during simulated cardiac arrest scenarios, which suggests that automating the process allows teams to spend less time discussing chest compressions and more time discussing the entirety of the clinical situation and reassessing the treatment plan. [16 Gittinger] While further research is needed on the impact of portable ventilators on the process of care, they have potential to automate stressful, difficult processes. This will likely improve the clinician's ability to focus on clinical decision-making and other critical tasks.

Overcoming Barriers to Mechanical Ventilation in EMS

Several perceived barriers have prevented EMS systems from widely adopting mechanical ventilation in the United States and other countries. While there are legitimate specific concerns, which are addressed below, each has to be weighed against the potential harm caused by wide variation in practice with manual ventilation, as well as the costs of continuous retraining to try to prevent that variation.

Infrequent provider use

Resuscitations and respiratory arrest patients requiring ventilation make up only a small percentage of emergent EMS responses. Although the exact number is not known, a study of national EMS data across 40 states reported that BVM/ventilation was performed 7.2 times for every 1000 EMS responses. This very likely represents an underestimate of the actual frequency, as endotracheal intubations attempts were reported in 8.3 cases per 100 responses, and CPR occurred in 8.7 per 1000 responses. [9 Carlson] Compared to such other critical procedures as manual defibrillation (3.8/1000), external cardiac pacing (0.7/1000) and cardioversion (0.3/1000), ventilation is a relatively frequent event.

With research showing that manual ventilation may be harming some of the most critical patients transported by EMS, use of mechanical ventilation for a small number of patients may still have a significant impact on outcomes. In addition, the need for prehospital ventilation may be increasing. For example, the number of people receiving invasive ventilation at home or in skilled-nursing facilities, while unknown, is believed to have increased significantly over the last two decades. [21 King, 39 Simonds] As more patients receive this treatment in the home, EMS clinicians will encounter them more often, leading to more frequent need for ventilator assistance during transport.

Additionally, mechanical ventilation may have a role in the non-intubated patient. Ventilators designed to work with a facemask or supraglottic airway can deliver more precise tidal volumes to patients without an ET tube. While further study is certainly needed, the delivery of optimal ventilation rates and volumes to any patient requiring breathing assistance, whether intubated or not, should be desired.

Cost

For many EMS systems, the purchase of any capital equipment can be a burden. However, as portable mechanical ventilators become more affordable, it is important to weigh the cost against the potential benefit, as well as the costs of other equipment. With multiple studies showing the need for frequent training to achieve optimal ventilation rates manually, there may also be a reduction in the total training time required to maintain proficiency. After recognizing the importance of consistent chest compressions, EMS systems have widely adopted mechanical CPR, despite a substantial cost to the devices. Mechanical ventilators offer many of the same benefits, with the possibility that they could be used with a wider number of patients. In addition, as reimbursement for prehospital care moves toward a value-based model, the use of mechanical ventilators to properly achieve and record certain quality metrics could be crucial.

Perceived complexity

Although the 2007 National EMS Scope of Practice Model stated that paramedics should be knowledgeable in use of automated transport ventilators, in many systems their use appears to be limited to critical care paramedics. Whether or not an EMS clinician learned about mechanical ventilation during their initial education, it is likely that not using and frequently re-training on ventilators would lead to a lack of comfort with their use. While there is no published evidence examining the comfort level of EMS clinicians with these devices, there is some evidence that paramedic training is not considered adequate. For example, at least one state requires an additional certification in order for paramedics to transport patients on mechanical ventilators. [45 Tennessee] And most critical care paramedic education programs focus significant amount of time on mechanical ventilator use—a possible acknowledgement that paramedic education does not adequately cover the topic.

However, the evidence described above shows that ventilation with a bag-valve system is more complicated than once believed, and often performed inadequately.

Studies have also shown that while retraining can help, it does not prevent hyperventilation or other errors, and must be conducted frequently. With the advent of safer and simpler portable ventilators, training EMS providers to use automated ventilators in specific clinical settings is quite possibly no more time consuming than training them to perform consistent, adequate and safe manual ventilations.

Weight

The burden of carrying an additional piece of equipment should not be minimized. EMS providers encounter patients in a wide variety of settings, often requiring the movement of equipment long distances and in limited space. However, as technology and engineering progresses, many of the devices carried in the prehospital setting are becoming more compact and lighter, including monitor/defibrillators, non-invasive ventilation (CPAP) and more. Ventilators are now also available in more lightweight and rugged forms than ever before, with some weighing less than two pounds.

Conclusion

Efforts to improve resuscitation of critical patients in the out-of-hospital setting have focused on reducing variability—from mechanical CPR to “pit crew” models, the importance of standardization and adherence to guidelines has been widely accepted. Yet decades of research has indicated that wide variance continues to occur in the practice of manual ventilation of cardiac arrest victims and other critical patients encountered by EMS clinicians—variance that has been associated with negative outcomes. Mechanical ventilation offers a solution to this variance and an opportunity to provide more consistent care adhering to evidence-based guidelines now and in the future.

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